

On the use of morphometric indicators to improve and simplify the interpretation of multibeam swath bathymetric data: case studies from volcanic and non-volcanic settings

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Abstract – The widespread, increasing availability of high-resolution multibeam swath bathymetric data in the last years provides an opportunity to study with unprecedented detail the seafloor morphology throughout the use of morphometric parameters. These are characterized by factors that help to highlight local or general properties of the seafloor both in coastal and deep marine environment as well as in volcanic and non-volcanic settings. Here, we show some tools used over the last ten years, either new or readjusted from previously existing, which helps to improve the interpretation and emphasize the results in terms of quantitative descriptions of the morphological features of marine landforms. We show the use of morphometric indicators to enhance: 1) the structural properties of seamounts; 2) the spatial arrangement and structural control on apparently chaotic sets; 3) the semi-automatic mapping such as the use of profile curvature to identify objects/targets outcropping from the seabed as archaeological outliers.

1. INTRODUCTION

Morphometric tools are quantitative parameters of Digital Terrain Models (DTMs) that help to highlight or to better understand the geometry and geomorphology of terrains by providing repeatable, quantifiable measures of shapes. The use of geomorphometry led to an improvement of the understanding of morphologic features, particularly in remote areas where data related to direct observations are poorly available, especially in both qualitative and quantitative approaches in regards to the marine environment [1]. The aim of this paper is to show some tools that we introduced in the last years. In particular, the tools summarized here are able to clarify: A) the presence of flat surfaces (e.g., marine terraces) and their to reconstruct the vertical displacement of an area; B) to highlight the existence of potential preferential pathways

arising from a structural control in apparently chaotic sets of features and C) the semi-automatic mapping tools such as the use of profile curvature to identify objects/targets outcropping from the seabed, such as man made outliers. In order to properly show these features, we will use three real case-studies: A) Palinuro Seamount, B) the Banco della Montagna volcanic high located in the Northern sector of Naples Bay, and C) the ruins of the Pozzuoli Baia underwater archaeological site, located in the northernmost sector of Pozzuoli Bay.

2. CASE STUDIES.

Gorringe Bank

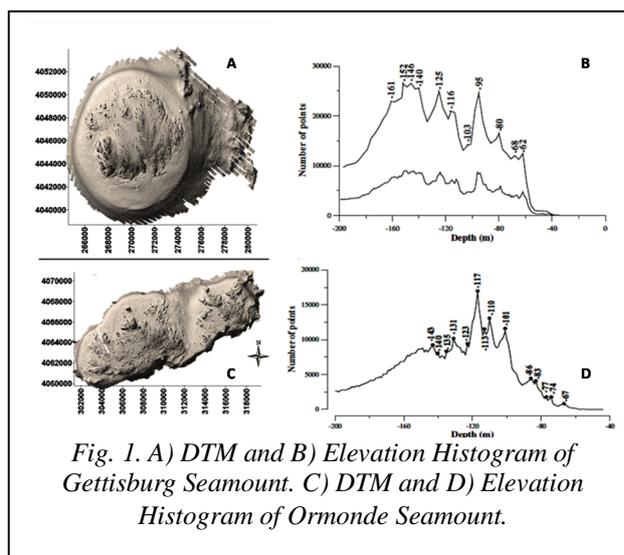


Fig. 1. A) DTM and B) Elevation Histogram of Gettysburg Seamount. C) DTM and D) Elevation Histogram of Ormonde Seamount.

The Gorringe Bank is a 140 km ENE-WSW striking bathymetric high that belongs to the Horseshoe submarine chain, located 300 km SW from the coast of Portugal. The bathymetric dataset of Gorringe Bank was

acquired during the Gorringe_2003 Cruise of the IAMC-CNR of Naples, by using a Reson Seabat 8101 multibeam equipment [2]. Its morphology consists in two summits, Gettysburg and Ormonde, whose tops reaches -27 and -30 m below sea level (bsl), respectively. Gettysburg and Ormonde highs are divided by a morphological saddle located at ≈ 1000 m bsl.

Terrace order	Ormonde Seamount	Gettysburg Seamount	Inferred age (ka b.p.)
M1	Absent	-42	192
T1	-47	-47	230
T2	-49	-49	230
M2	-52 (-56)	Absent	
T3	-61	-62	88
T4	-67	-68	38 or 55
T5	-77 (-74)	-79	168
M3	-83 (-86)	Absent	
T6	-101	-95	178
T7	-110 (-113)	-113 (-116)	220
M4	-117	?	
T8	-123	-125	19
M5	-131 (-135)	Absent	
T9	-143 (-140)	-140 (-146; -152)	244
M6	Absent	-161	

Tab.1 Marine terraces elevation derived by elevation histogram

The final Digital Terrain Model (DTM) of Gettysburg Seamount consists of 170 km² with 10 m grid cell size, (bathymetric range is -27/-400 m bsl), here presented. The Ormonde Seamount dataset consists of 120 km², located in the -33/-420 m bsl (grid cell is 10m).

Both the Gettysburg and Ormonde summits are located in a bathymetric range that allowed the set up of coastal processes linked to sea-level stands of the global sea-level curve, which led to the formation of several order of terraces on their flanks. It is worth noting that marine terraces are optimal indicators for the quantitative evaluation of vertical rate of movements [3]. The challenge for this study was to find the height of marine terraces and their possible relations with uplift/subsidence rates of the whole Gorringe Bank.

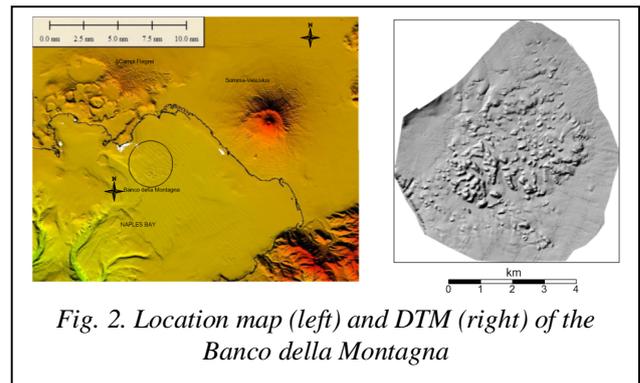
To address this task, we used the computation histogram of elevations, which consists in a simple plot of elevation versus their percentage of the area. In this plots, the presence of a specific value of elevation in the DTM is reported as its relative abundance with respect to the other values. Consequently, flat surfaces (like marine terraces) result in relative maxima. Thanks to the obtained graphs, we found several pikes (Fig. 1, A-D) corresponding to potential records of sea-level still-stands. The comparison of the global sea level curve of Waelbroek allowed to check the available orders of terraces that were exposed on Gettysburg and Ormonde (Tab.1) and to evaluate the subsidence rate of the edifice,

that resulted to be about 0.1 mm/y. The obtained result were confirmed by studying marine terraces with geomorphologic inspection of DTM [4, 5].

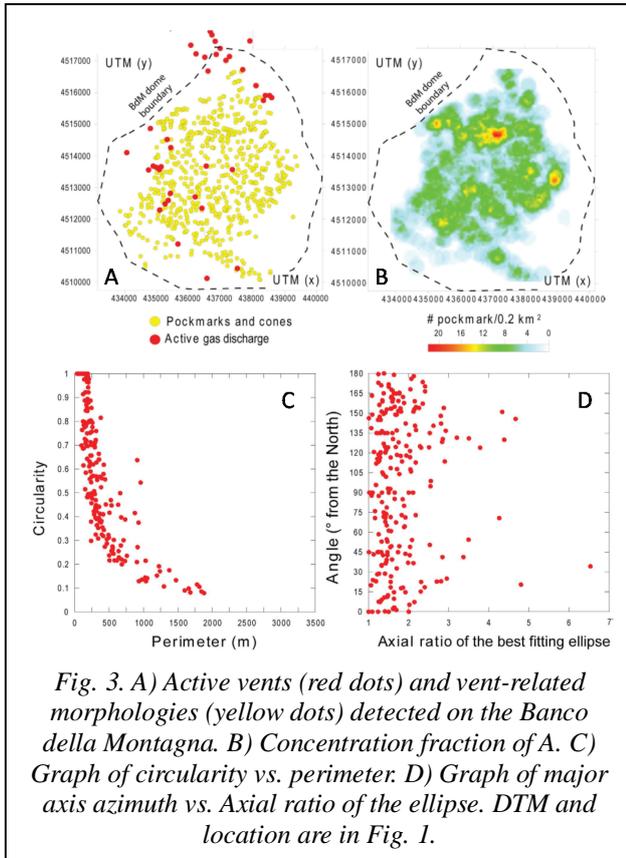
Banco della Montagna

The Northern sector of Naples Bay (Fig. 2A) is characterized by the presence of some active and hazardous volcanic edifices, Campi Flegrei (from about 300 ka to 1538 AD), Somma-Vesuvius. (from < 360 ka to 1944 AD) in particular. Huge hydrothermal activity (CO₂ output up to 1500 t/d), ground deformations (e.g., bradyseism with an uplift of 1.8 m during the 1982-1984 unrest episode), seismic activity and slides are some of the multiple, hazardous effects directly linked to the still active volcanic nature of this area.

Multibeam data acquisition was carried out during the SAFE_2014 oceanographic cruise onboard of the Minerva Uno oceanographic vessel (CNR) with the use of a 100 KHz Simrad EM710 multibeam sonar system (Kongsberg). A sub-circular morphological high called Banco della Montagna (BdM) was mapped with a very high resolution DTM (1 m) during the cruise. BdM extends over an area of about 16 km² (Fig. 2 B), characterized by a mound-like morphology. Pumices-sandy diapiric structures that rise through the upper Holocene deposits compose the rugged shaped top of BdM [6]. We recognize 37 gas emissions from echosounder images of the water column and direct observations on the sea bottom with ROV acquired during the SAFE_2014 cruise. The acoustic anomalies of these emissions show vertically elongated shapes upraising from the seafloor and a height between 12 and



about 70 m [7]. In some places, the acoustic anomalies form nearly continuous 'trains'. BdM top is also characterized by the presence of several morphologies that are typically associated to gas vents, i.e. mounds, small cones and pockmarks.



The DTM allow us to map 280 sub-circular to elliptical mounds, 665 cones and 30 pockmarks (Fig. 3A). One of the major challenge in such a case was to identify preferential patterns that ruled the emplacement of fluid vent-morphologies. Despite their apparent chaotic disposal, a first result was obtained by calculating the spatial density of the cones and pockmarks, which evidenced major NW-SE alignments delimiting the northeastern and southwestern boundary of the dome and subordinate (and less extended) NE-SW (Fig. 3B). In addition, we highlighted some characteristics of dimension and shape of these features by plotting their circularity vs. perimeter and the azimuth angle of the major axis (for the elliptic shapes) perimeter of morphologies. These plots demonstrated that features with larger perimeter were characterized by minor values of the index of circularity (Fig. 3C). Moreover, shapes with larger differences between the major and the minor axis (i.e., less circular) align along the same orientations defined by the spatial density of cones (Fig. 3D). These elements led to infer a definitive structural control from NW-SE and NE-SW structures, that also correspond to the main tectonic alignments of the Naples Bay.

Pozzuoli-Baia underwater archaeological site

The Pozzuoli Bay (Fig. 1) is the offshore counterpart of

the Campi Flegrei caldera, a volcanic district located in the Neapolitan area, characterized by a complex set of vertical ground movement called bradyseism (Fig. 4A). Bradyseism consists of a set of spot uplifting crises inside an overall sinking of the caldera. As a consequence of both the CF subsidence and sea level rise, the coastline of Baia-Pozzuoli receded of several meters in the last ≈ 2 Ka. several archaeological ruins are also located in this area. They constitute the Pozzuoli-Baia underwater archaeological site. The archaeological find (Fig. 4B) belongs to the ancient Puteoli (the actual Pozzuoli) harbour, which was initially a military complex later converted in a commercial one. The site also includes Baianus Lacus (Baia), essentially made of Villas luxury buildings (e.g. Villa a Protiro, Pisonian Villa, etc.). These were sites of several thermal complexes [8]. Multibeam swath bathymetric data were acquired in this area from CNR between 2003 and 2005 by using the Reson Seabat 8111 and the Reson Seabat 8125 multibeam equipments. The resulting Digital Terrain Model (DTM; Fig. 4) was obtained by merging the results of several surveys. Despite the multibeam bathymetry was potentially characterized by a lower average nadir footprint value (about 1.5 m) in the archaeological area, the limitation induced from the GPS positioning precision results in a metrical spatial uncertainty of beam positioning, that can not be resolved with a lower than 5x5m grid cell size. Due to their importance, archaeological remains were mapped as “outliers” by using a morphologic inspection of DTM, that was not satisfying. Thus, a GIS procedure was developed by using the GRASS GIS Open Source package. A spatial re-sampling of data was initially carried out. DTM grid cell spacing was reduced from 5 m to 1 m by linear interpolating them by means of regularized spline with tension interpolator. Thus, the calculation of the profile curvature of the DTM was made by using the “r.param.scale”, that allowed to highlight local “outliers” (Fig. 4C). Profile curvatures highlight the presence of objects that rise up from the surrounding seafloor as “positive” shapes (that correspond to convex profile curvature). Conversely, concave shapes of the calculated profile curvature are “negative” morphologies. We obtain the final mapping by joining the profile curvature and the slope map, where high slope gradients are mainly concentrated on the border of the archaeological outliers (Fig. 4C). The contour map of the obtained numerical matrix allowed to distinguish the man made objects elevating from the seafloor.

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